# INDOOR AIR QUALITY ASSESSMENT

**Gloucester High School**
**Administration and Guidance Offices**
**32 Leslie O. Johnson Road**
**Gloucester, Massachusetts**

Prepared by:
Massachusetts Department of Public Health
Center for Environmental Health
Emergency Response/Indoor Air Quality Program
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## Background/Introduction

At the request of Brian Tarr, Assistant Superintendent, Gloucester Public Schools (GPS), the Massachusetts Department of Public Health (MDPH), Center for Environmental Health's (CEH's) Bureau of Environmental Health Assessment (BEHA) provided assistance and consultation regarding indoor air quality concerns at in the administration and guidance offices of Gloucester High School (GHS), 32 Leslie O. Johnson Road, Gloucester, Massachusetts. The request was prompted by reported complaints of possible mold growth on floors when the air-conditioning system is activated.

During the summer of 2004, visits to conduct an indoor air quality assessment at the administration wing of GHS were made by Michael Feeney, Director of the BEHA's Emergency Response/Indoor Air Quality Program (ER/IAQ). Mr. Feeney visited the GHS on June 18, 2004.and returned to the building with Sharon Lee, Environmental Analyst of the ER/IAQ Program, on August 4, 2004 to observe the conditions of the administrative building with the air-conditioning system activated during hot, humid weather.

BEHA staff previously conducted a series of visits in 1997 to assess indoor air quality in the occupied section of the building, while the building was under renovation. A report was issued detailing indoor air quality conditions in the school at that time (MDPH, 1997). At the time of the 2004 assessments, that renovation project had been completed.

The school is a multi-wing, brick building renovated from 1996 to 1998. The administration and guidance/counseling offices (the offices) are located on the first floor of a two-story wing that was added during the renovation project (Picture 1). The administration office and guidance/counseling suites are separated by a corridor that opens into the foyer entrance of the building. The faculty workroom is also located in this first floor area. The school library is located on the second floor above the offices. The library, offices and faculty workroom are air-conditioned during the summer. The remainder of the high school is *not air-conditioned*. Administration offices do not have openable windows; however, private offices in the guidance/counseling office do.

## Methods

Air tests for carbon monoxide, carbon dioxide, temperature and relative humidity were taken with the TSI, Q-Trak, IAQ Monitor, Model 8551. Water content of building components was measured with a Delmhorst, BD-2000 Model, Moisture Detector equipped with a Delmhorst Standard Probe. Surface temperature of building components was taken with a Thermotrace laser thermometer.

## Results

The administration and guidance/counseling offices have a staff of approximately 15. Tests were taken during normal summer operations. Test results appear in Tables 1-4.

## Discussion

### Ventilation

It can be seen from Tables 1-3 that carbon dioxide levels were below 800 parts per million (ppm) in all areas surveyed on both dates, which indicate adequate fresh air supply at the time of the assessments. It should be noted, however, that areas were sparsely populated and windows to private offices in the guidance/counseling suite were open, which can greatly contribute to reduced carbon dioxide levels.

A heating, ventilation and air conditioning (HVAC) system provides ventilation to the offices and library. Fresh air is provided by a rooftop-mounted air-handling unit (AHU) (Picture 2). The AHU is connected to ducts that supply fresh air to rooms via ceiling mounted air diffusers. By design, air diffusers are equipped with fixed louvers. These louvers direct the air supply to travel along the ceiling and down the walls, thereby creating airflow. Exhaust ventilation is provided by infiltration of air into the ceiling plenum, which is a space between the ceiling tile system and floor above. Air from the ceiling plenum is returned to the AHUs. This system has no ductwork, but uses the entire space above the ceiling tile system to return air to the AHU.

In order to have proper ventilation with a mechanical supply and exhaust system, these systems must be balanced to provide an adequate amount of fresh air to the interior of a room while removing stale air from the room. It is recommended that existing ventilation systems be re-balanced every five years to ensure adequate air systems function (SMACNA, 1994). According to GPS officials, the date of the last balancing of these systems occurred in 1998, when renovations were completed.

The Massachusetts Building Code requires that each room have a minimum ventilation rate of 20 cubic feet per minute (cfm) per occupant of fresh outside air or openable windows (SBBRS, 1997, BOCA, 1993). The ventilation must be on at all times that the room is occupied. Providing adequate fresh air ventilation with open windows and maintaining the temperature in the comfort range during the cold weather season is impractical. Mechanical ventilation is usually required to provide adequate fresh air ventilation.

Carbon dioxide is not a problem in and of itself. It is used as an indicator of the adequacy of the fresh air ventilation. As carbon dioxide levels rise, it indicates that the ventilating system is malfunctioning or the design occupancy of the room is being exceeded. When this happens, a buildup of common indoor air pollutants can occur, leading to discomfort or health complaints. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million parts of air (ppm). Workers may be exposed to this level for 40 hours/week, based on a time-weighted average (OSHA, 1997).

The Department of Public Health uses a guideline of 800 ppm for publicly occupied buildings. A guideline of 600 ppm or less is preferred in schools due to the fact that the majority of occupants are young and considered to be a more sensitive population in the evaluation of environmental health status. Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches. For more information concerning carbon dioxide, consult Appendix A.

Temperature measurements ranged from 69$^{o}$ F to 71$^{o}$ F on June 18, 2004 and from 69$^{o}$ F to 75$^{o}$ F on August 4, 2004. These measurements were within or slightly below the BEHA recommended comfort range. The BEHA recommends that indoor air temperatures be maintained in a range of 70$^{o}$ F to 78$^{o}$ F in order to provide for the comfort of building occupants. In many cases concerning indoor air quality, fluctuations of temperature in occupied spaces are typically experienced, even in a building with an adequate fresh air supply.

The relative humidity measured in the building ranged from 67 to 71 percent on June 18, 2004, except in the library which had a relative humidity of 59 percent. On August 4, 2004, relative humidity in the building ranged from 57 to 71 percent, again with exception to the library which had a relative humidity of 56 percent. Relative humidity measurements were above the BEHA recommended comfort range in a number of areas on both days of indoor air sampling. The BEHA recommends a comfort range of 40 to 60 percent for indoor air relative humidity. Relative humidity levels in the building would be expected to drop during the winter months due to heating. The sensation of dryness and irritation is common in a low relative humidity environment. Low relative humidity is a very common problem during the heating season in the northeast part of the United States.

The differences in relative humidity between the first floor air-conditioned offices and second floor library are noteworthy. The offices had relative humidity levels comparable to outdoor levels on both assessment days (outdoor levels were 71 percent and 66 percent on June 18, 2004 and August 4, 2004, respectively). In contrast, relative humidity levels in the library were, in many cases, at least 10 percent less than office levels. The rooftop AHU servicing the library appears to be identical to the AHU that services the offices; both units provide fresh air and are equipped with chillers for air-conditioning during the summer. When AHUs are operating, indoor relative humidity measurements should be lower than outdoor relative humidity. The reduced relative humidity seen in the library during air-conditioning is expected in an environment with an appropriately functioning AHU.

Possible reasons for the excessive relative humidity measured in the first floor offices may be the combination of the office ventilation system function and the design of the HVAC system. As discussed, AHU are designed to provide tempered (heated or cooled) fresh air to an area with a specific volume of air. AHUs with cooling capabilities are equipped with thermostats. These thermostats are calibrated to ensure that the chiller will become activated or deactivated once a set temperature point is met. When the temperature point in the unit is exceeded, the chiller is activated. Once the temperature drops below the set point, the chiller is deactivated until the temperature rises above the set point to activate the chiller. This cycled chilling sequence operates appropriately in areas with a *defined, set volume of air* that corresponds to the design capacity of the AHU. For example, the library's AHU is balanced to provide conditioned air for *only* the library area (including the adjoining classrooms). The library area is a space with a relatively closed, defined volume.

In contrast, the AHU servicing first floor offices does not appear to provide air to an enclosed, defined environment with a fixed volume. As a general rule, areas that *are* air-conditioned should be physically separated from areas that *are not* air-conditioned. Such physical separation is necessary to prevent the draw of unconditioned air to the AHU from areas that are not air-conditioned. The following observations support the conclusion that the AHU servicing the first floor offices does not draw air to an enclosed, defined environment with a fixed volume:

- As discussed, the administration and guidance/counseling offices are separated by a hallway (Picture 3). One end of the hallway opens to the building entrance foyer, the other into a hallway of the original building (Picture 4). The hallway leading to the old building is open, with no fire doors to partition the administration wing from the old building. The old building is not air-conditioned. The fresh air supply vents for the offices' hallway are connected to the offices' AHU. Therefore, chilled air is directed into the hall. The hallways, including the administration wing hallway, are not designed to be air-conditioned space.
- As discussed, air is drawn through plastic ceiling grates and returned to the AHU via the ceiling plenum, rather than by ductwork. BEHA staff found that the ceiling plenum in the offices' hallway was open to the ceiling plenum above non-conditioned sections

building. In this condition, the offices' AHU is drawing air from the ceiling plenum of the *entire* first floor. Since the ceiling plenum is an open space, unconditioned air from the ceiling plenum above classrooms and hallways is also returned to the AHU. It appears that a polyethylene plastic and duct tape "wall" was constructed to separate the offices' ceiling plenum from the plenum above unconditioned spaces (Picture 5). When this "wall" failed, unconditioned air was drawn into the offices' AHU.

- Fibrous glass insulation bats were installed in the ceiling plenum between wall studs that hold the offices' hallway walls in place (Picture 6). The purpose of the fiberglass bats may have been to form a closed ceiling plenum for the administration and guidance suites that would be separate from the hallway ceiling plenum. These fiberglass bats were not affixed and had fallen from the metal studs, creating large openings for hallway air to be drawn into the offices' ceiling plenum.
- The ceiling plenum was created by installing a suspended ceiling tile system below the original plaster ceiling in the hallways and classrooms of the original building. It appears that large holes were made in the plaster ceiling in order to install chains from which the suspended ceiling would hang (Picture 7). These holes create a breach through which unconditioned air above the original plaster ceiling can be drawn.

Each of these conditions provides opportunities for unconditioned air to be returned to the offices'AHU.

When an uncontrolled source of warm air is drawn into the AHU, the chiller will not shut down since the thermostat for this equipment continuously measures air temperatures that require conditioning. As a result, the chiller continuously operates. Therefore, air in occupied spaces becomes colder and colder as the day progresses. In an effort to chill air, the dampers of the fresh air intakes for the AHU will close, minimizing the amount of fresh air drawn into the unit. Rather than providing cooled fresh air, the AHU recirculates air. Decreased temperature and reduced fresh air supply can produce discomfort in building occupants. GPS administration received numerous reports regarding temperature and relative humidity discomfort. Prior to the BEHA 2004 assessments, GPS staff reportedly made numerous attempts to service and adjust the AHU servicing the offices to ensure the equipment provides appropriate control of temperature and relative humidity.

**Microbial/Moisture Concerns**

Operating the offices' AHU in a plenum where unconditioned air from other sections of the building is drawn into the AHU can facilitate the potential for moisture accumulation and microbial growth in porous materials. As reported by GPS staff, the floor of the administration office becomes slick with water during hot, humid weather. Staining along floor tile seams and cracks in the floor, confirm that standing water accumulates on the floor. Water accumulation on the floors and staining between floor tiles is most likely due to condensation. The material observed between tiles is likely floor tile mastic that expanded when exposed to accumulating moisture.

The primary source of moisture appears to be the AHU drawing air from the ceiling plenum, which is open to unconditioned areas of the building. When warm, moist air passes over a surface that is colder than the air, water condensation can collect on the cold surface. Over time, water droplets can form. Condensation is the collection of moisture on a surface at or below the dew point. The dew point is the temperature that air must reach for saturation to occur. The dew point is a temperature determined by air temperature and relative humidity. If a surface has a temperature equal to or below the dew point, condensation will accumulate. For example, at a temperature of 70° F and indoor relative humidity of 63 percent, the dew point for water to collect on a surface is approximately 57 ° F (IICR, 2000). Therefore, any surface that has a temperature below 57 ° F would be prone to condensation generation under these temperature and relative humidity conditions. Surfaces in direct contact with soil (e.g., foundations) will tend to have a surface temperature significantly lower than other building components. Area such as tiles on slab floors, walls directly cooled by chilled ventilation air (e.g., vice principal's office) or uninsulated steel support beams (e.g., ceiling plenum above the guidance office conference room) (Picture 8) may all be prone to generating condensation. At the time of the August 2004 assessment, no active water leaks were observed, and no visible, accumulated moisture was noted on floors, walls or ceilings.

To determine the dew point of the floor surfaces, BEHA staff took temperature measurements of office floors. Dew point of the floor can than be calculated based on the floor surface temperature and the relative humidity of the room. Relative humidity measured in the office areas ranged from 57 to 71 percent on the first floor, 56 percent in the library. Floor surface temperature measurements revealed that some office floors were near, at or below the estimated dew point during the August 2004 assessment (Table 3). If the floor temperature measured during the assessment is typical of these surfaces during the summer, it is reasonable to assume that condensation generation is the most likely source of water slicking the floor.

During the normal operation of a HVAC system, moisture is introduced into a building during weather with high relative humidity. As relative humidity levels increase indoors, porous building materials, such a gypsum wallboard (GW), can absorb moisture. The moisture content in GW can fluctuate with increases/decreases in indoor relative humidity. Moisture sampling was conducted to ascertain moisture content of materials most likely to support mold growth [e.g., (GW)]. The moisture sampling was conducted on a clear day, with an outdoor temperature of 61 $^{o}$ F and relative humidity of 71 percent. Moisture sampling was conducted in interior walls of the first floor offices and, for comparison, in library walls.

A Delmhorst probe was inserted into the surface of GW. The Delmhorst probe is set to sound a signal when moisture reading $\geq$ 0.5 percent in GW is detected. Moisture readings are listed by room in Table 4. A total of 15 areas were evaluated. Moisture content of GW within the normal range (0.3 percent) was measured in the two areas of the library sampled. In contrast, the rooms in the administration and guidance suites had GW with moisture content measurements over $\geq$0.6 percent (Table 4), which suggests dampening by a water source (e.g., increased indoor relative humidity, see Ventilation section).

The US Environmental Protection Agency (US EPA) and the American Conference of Governmental Industrial Hygienists (ACGIH) recommends that porous materials be dried with fans and heating within 24-48 hours of becoming wet (US EPA, 2001; ACGIH, 1989). If porous materials are not dried within this time frame, mold growth may occur. Water-damaged porous materials cannot be adequately cleaned to remove mold growth. The application of a mildewcide to moldy porous materials is not recommended.

## Conclusions/Recommendations

Based on the observations made at the time of the assessments, the origin of the water accumulation problems in the administration office appears to be the operation of the AHU in its air-conditioning mode during hot, humid weather. The combination of operating the air-conditioning system in an open-ended hallway and failure to establish/maintain a permanently closed ceiling plenum results in the continuous operation of the AHU chiller. Continuous chilling lowers the temperature of building components below the dew point thereby resulting in condensation formation. A two-phase approach is required to address general indoor air quality and moisture problems experienced in the administration wing of the GHS. This approach consists of short-term recommendations to improve air quality at the school and long-term measures that require planning and resources to adequately address overall indoor air quality concerns.

In view of the findings at the time of these visits, the following **short-term** measures should be considered for immediate implementation:

1. Refrain from operating the chiller system of the AHU servicing first floor offices until the ceiling plenum is permanently closed.
2. Replace GW noted by GPS staff to have been wet or mold colonized.
3. Insulate the beam above the return vent in the guidance suite conference room to prevent condensation formation. The GW below this beam should be replaced.
4. Open windows in the guidance office to increase airflow when air-conditioning is not in use. When air-conditioning is operating, close windows.

**Long Term Recommendations**

The long term recommendations provided relate to establishing a defined volume of air for the offices' AHU to condition. There are a number of options available to achieve this goal. Each option should be examined in consultation with a building and/or HVAC engineer.

1. Prevent unconditioned air from entering the offices' AHU. This goal can be accomplished by, but not limited to, the following options:
    a. Install insulated ductwork to connect each return vent to the rooftop AHU.
    b. Install fire doors at the open end of the offices' hallway to establish a *closed* air-conditioning zone. The door frame (or similar barrier) should be extended through the ceiling plenum and original ceiling to prevent the draw of unconditioned into the ceiling plenum. This option would establish a fixed volume of air for the ceiling plenum. With this option, it would be advisable to move the door from its original location to open into the air-conditioned hallway. The door relocation would then place the faculty lounge within the air-conditioned zone and prevent draw of unconditioned air from the hallway.
    c. Install permanent insulated walls in the ceiling plenum above hallway walls where fiberglass insulation bats have fallen. Once in place, hallway fresh air diffusers should be disconnected from the offices' AHU. Diffusers should be replaced with ceiling tiles.
2. Seal all holes made in the original ceiling to prevent draw of unconditioned air into the ceiling plenum of *first and second floor* rooms in the air-conditioned zone.
3. Balance the offices' ventilation system once the offices' air volume is permanently established.
4. Consider raising the set point that activates chiller when the ventilation system is balanced. A raised set point would prevent the temperature of building components from cooling below the due point.

5. Replace the fresh air diffuser in the assistance principal's office with a three-way air diffuser to limits cold air contact with the GW walls.
6. Examine the wall space between the guidance office and the electrical shop to determine if proper insulation exists.

## References

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**Picture 1**

**Library, Administration and Guidance Wing**

**Picture 2**

**Offices AHU**

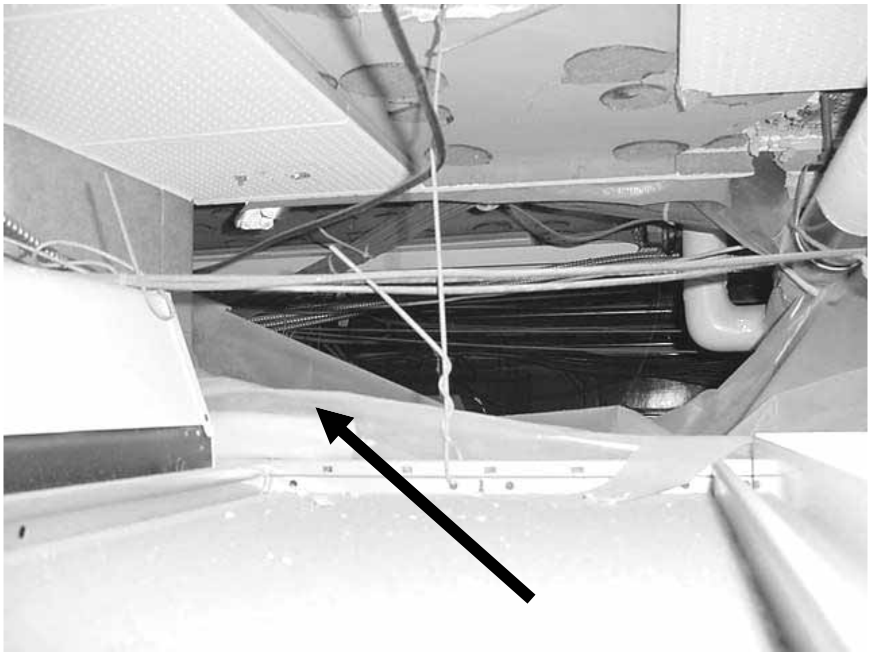
**Picture 3**

**Offices' Hallway**

**Picture 4**


**End of Offices' Hallway That Is Open to Old Building (Dotted Line Indicates Approximate Demarcation Between Air-Conditioned and Non-Air-Conditioned Space)**

**Picture 5**

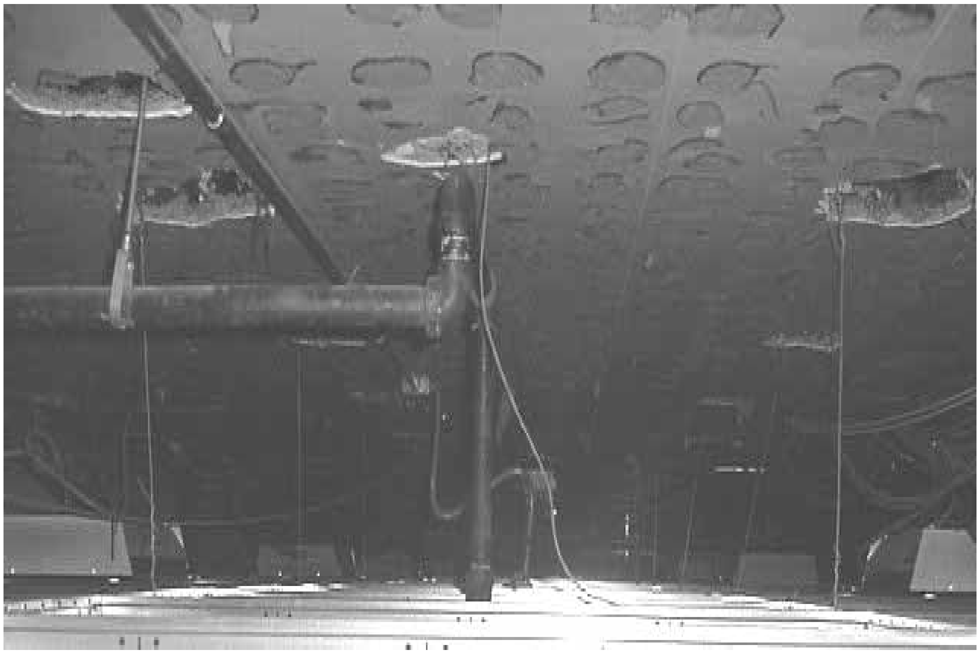


**Plastic And Duct tape Above the Open End of the Office's Hallway at the Approximate Demarcation between Air-Conditioned and Non-Air-Conditioned Space**

**Picture 6**

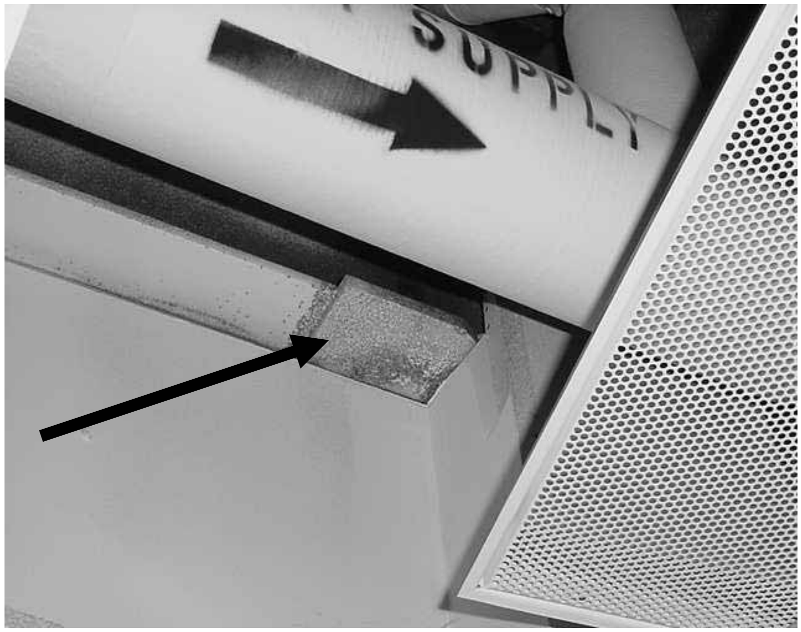
**Fallen Fibrous Glass Bats above the Office's Hallway Walls**

**Picture 7**



**Hole Punched Into Original Ceiling In Order To Hang Suspended Ceiling, Sprinkler Pipes, Etc.**

**Picture 8**




**Rust Steel Beam above Mold Colonized GW in Guidance Suite Conference Room**

**Gloucester High School**
**Administration and Guidance Offices**
**32 Leslie O. Johnson Road, Gloucester, MA**

**Indoor Air Results**
**June 18, 2004 AM**

# Table 1

| Location | Carbon Dioxide (*ppm) | Temp. (°F) | Relative Humidity (%) | Occupants in Room | Windows Openable | Ventilation | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Supply | Exhaust | |
| Outside (Background) | 396 | 67 | 71 | | | | | |
| 1301B Administration Office workroom | 694 | 69 | 71 | 0 | N | Y | Y | Condenation stains on floor |
| 1302C | 641 | 70 | 75 | 1 | N | Y | Y | Door open |
| 1303A | 775 | 70 | 72 | 1 | N | Y | Y | Door open<br>3 water damaged ceiling tiles |
| 1303B | 771 | 69 | 74 | 1 | N | Y | Y | |
| 1307 | 613 | 70 | 72 | 2 | N | Y | Y | |
| 1403 | 467 | 70 | 71 | 2 | Y | Y | Y | Window open |
| Library | 578 | 70 | 59 | 20+ | Y | Y | Y | 3 water damaged ceiling tiles<br>2 missing ceiling tiles |

*** ppm = parts per million parts of air**

**Comfort Guidelines**

| | |
|---|---|
| Carbon Dioxide - | < 600 ppm = preferred<br>600 - 800 ppm = acceptable<br>> 800 ppm = indicative of ventilation problems |
| Temperature - | 70 - 78 °F |
| Relative Humidity - | 40 - 60% |

**Gloucester High School**
**Administration and Guidance Offices**
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**Indoor Air Results**
**June 18, 2004 PM**

## Table 2

| Location | Carbon Dioxide (*ppm) | Temp. (°F) | Relative Humidity (%) | Occupants in Room | Windows Openable | Ventilation | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Supply | Exhaust | |
| Outside (Background) | 392 | 68 | 72 | | | | | |
| Main Office | 516 | 71 | 69 | 2 | N | Y | Y | |
| 1303A | 604 | 71 | 69 | 0 | N | y | y | |
| 1303C | 546 | 71 | 70 | 2 | N | y | y | |
| 1303B | 545 | 70 | 68 | 0 | N | Y | y | |
| 1301B | 535 | 70 | 68 | 0 | N | y | y | Door Open |
| Mail box area, main office | 495 | 69 | 67 | 0 | N | Y | Y | |
| 1204 | 555 | 70 | 68 | 1 | N | Y | Y | Door Open |
| 1202A | 569 | 70 | 69 | 0 | N | Y | Y | Door Open |

*** ppm = parts per million parts of air**

**Comfort Guidelines**

| | |
|---|---|
| Carbon Dioxide - | < 600 ppm = preferred |
| | 600 - 800 ppm = acceptable |
| | > 800 ppm = indicative of ventilation problems |
| Temperature - | 70 - 78 °F |
| Relative Humidity - | 40 - 60% |

**Gloucester High School**
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**Indoor Air Results**
**June 18, 2004 PM**

# Table 2

| Location | Carbon Dioxide (*ppm) | Temp. (°F) | Relative Humidity (%) | Occupants in Room | Windows Openable | Ventilation | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Supply | Exhaust | |
| 1202C | 492 | 69 | 68 | 0 | N | Y | Y | Door Open |
| 1302 | 511 | 69 | 71 | 0 | N | Y | Y | |
| 1302F | 499 | 69 | 71 | 0 | Y | Y | Y | Door Open |
| 1302B | 594 | 70 | 70 | 1 | Y | Y | Y | Door Open |
| 1307 | 530 | 70 | 69 | 3 | N | Y | Y | |

*** ppm = parts per million parts of air**

**Comfort Guidelines**

| | |
|---|---|
| Carbon Dioxide - | < 600 ppm = preferred |
| | 600 - 800 ppm = acceptable |
| | > 800 ppm = indicative of ventilation problems |
| Temperature - | 70 - 78 °F |
| Relative Humidity - | 40 - 60% |

Gloucester High School
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**Temperature and Relative Humidity Results**

**August 4, 2004**

# Table 3

| Location | Temp. (°F) | Relative Humidity (%) | Estimated Dew Point (°F) | Floor Temp. (°F) |
|---|---|---|---|---|
| Outside (Background) | 78 | 66 | | |
| 1303A | 74 | 59 | 58 | 63 |
| 1303 Assistant Principal | 74 | 58 | 57 | 63 |
| 1303C | 73 | 57 | 57 | 58 |
| 1303B | 69 | 64 | 54 | ***53**** |
| 1301B | 71 | 59 | 53 | 54 |
| 1302 | 70 | 68 | 60 | 63 |
| 1302A | 71 | 71 | 63 | ***63**** |
| 1302B | 71 | 71 | 63 | ***61**** |
| 1302F | 70 | 68 | 58 | 56 |
| 1307 | 72 | 67 | 61 | 62 |
| 1206 | 72 | 60 | 58 | 60 |
| Main Office | 73 | 59 | 59 | 60 |
| Library computer area | 75 | 56 | 56 | 75 |
| Library at hallway exit | 75 | 56 | 56 | 75 |
| 1301a | 72 | 57 | 53 | 55 |

*Highlighted floor temperature measurements indicate a temperature measured at or below the estimated dew point

**Comfort Guidelines**

| | |
|---|---|
| Temperature - | 70 - 78 °F |
| Relative Humidity - | 40 - 60% |

Gloucester High School
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32 Leslie O. Johnson Road
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Gypsum Wallboard (GW) Moisture Content Sampling
August 4, 2004

# Table 4

| Location | Moisture Content (%) |
|---|---|
| 1303A | 0.6 |
| 1303 Assistant Principal | 0.6 |
| 1303C | 0.6 |
| 1303B | 0.5 |
| 1301B | 0.4 |
| 1302 | 0.6 |
| 1302A | 0.4 |
| 1302B | 0.6 |
| 1302F | 0.7 |
| 1307 | 0.4 |
| 1206 | 0.7 |
| Main Office | 0.6 |
| Library computer area | 0.3 |
| Library at hallway exit | 0.3 |
| 1301a | 0.6 |

**Guidelines**

| | |
|---|---|
| Moistened | $\geq$ 0.5 percent |